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Fish Welfare

By

HAROLD THOMPSON

Chief of the Division of Fisheries, C.S.I.R.

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PLATES I-III

SOME GENERAL CONSIDERATIONS

It is proposed in this lecture to make some examination of the responses of fish populations to influences brought to bear upon them in their physical and animate environments. I hope to focus particular attention on the relationship between research findings and fisheries' management and exploitation. Although I shall draw on almost world-wide sources for my examples, most of what is said will, I think, bear application to Tasmanian fisheries. The latter are an important factor in the economy of this sea-girt State and are, it is pleasing to note, at present in a phase of expansion. My remarks will, I trust, show that it is essential to ensure that such expansion must proceed rationally, guided by basic principles now well-established—principles which are in harmony with such as were espoused by the late Mr. Clive Lord, in whose memory this lecture is given, and to whose great work for science in Tasmania so much is due.

In his R. M. Johnston Memorial Lecture delivered to this Society, Professor W. J. Dakin (1934) dealt very fully with the great advances which had been made in fisheries' science in preceding, though comparatively recent, years. More than a decade has passed since this lecture was given, and we have had a second opportunity of witnessing, after a prolonged war period, the results of compulsory restriction on man's fishing efforts. Some apparently fundamental principles, which had required a more prolonged period of testing out, have now become firmly established in this intervening period. I shall therefore endeavour to illustrate, as far as possible from my own direct association with fisheries' research in several widely separated countries, some of these cardinal principles which, to a large extent, govern the welfare of fish stocks.

Great numbers of fish species have been described by taxonomists, each species being recognisable by certain body characters fixed within certain limits—characters such as size, shape, number of vertebrae, number of fins and of finrays, nature of dentition and so forth. Within these limits, as we shall see later, it is sometimes possible to recognise races exhibiting more or less constant minor variations in these characters. Thus it is that experienced fishermen in, say, Newfoundland, pride themselves on being able to say, from superficial examination of a catch of codfish brought to market, from what part of the coast this catch has come. They easily differentiate the round-snouted, plump, fast-growing cod of the Grand Banks from the sharp-snouted, comparatively lean or slinky, slow-growing cod from the deep bays or from Labrador. The general positon is that certain species have become established, in greater or lesser numbers, to suit the conditions in particular environments. Thus we identify the cod as being the characteristic fish of Norway and Newfoundland, just as the barracouta appears to be the most prolific fish in

Tasmanian waters. In general, the rule holds that in the colder waters of high latitudes there are comparatively few fish species—e.g., cod, haddock, herring—but great numbers of each, whereas in tropical and sub-tropical seas there are great numbers of different species but no colossal quantities of any one species. Thus fewer than 100 fish species have been found in Newfoundland waters, whereas over 2000 species have been identified in Australian waters. In the latter, following the same rule, the number of species decreases from about 1900 in Queensland waters to about 700 off New South Wales and still fewer in the colder Tasmanian waters. Nor is it possible to introduce a prolific cold water species to warmer waters—for example, any effort to introduce the ordinary herring of commerce, the most prolific fish in north boreal waters, to Australian waters would almost inevitably fail, owing to the wide difference in temperature conditions between the two areas. It is also highly questionable whether this fish could be introduced to waters of suitable temperature conditions in the Antarctic, since other necessary conditions may well be lacking—for example, suitable sea-floor conditions for the deposition of eggs, and suitable food supplies for the developing and for adult fish themselves. I have myself participated in an experiment designed to effect the transplantation of a fish much esteemed in the Billingsgate Market—the Dover or Black Sole—over a distance of a mere few hundred miles from the East Anglian Coast to the Firth of Forth in Scotland. The effort was a total failure—we transferred several hundred of the soles, each carrying a tag for its identification should it be recaptured, to the Firth. No trace of these tagged soles was ever discovered. It is a fair deduction that the new environment was unsuitable for the soles and that they failed to survive.

In the case of marine fish it appears to be extremely difficult to effect the colonisation of new environments, whereas, of course, it has been found possible to achieve success in introducing certain fresh-water fish such as trout. The degree of success is, however, much less in the case of fish such as the true salmons, which under natural conditions spend a considerable portion of their life at sea.

Effects of Physical Conditions

1. *Effect of Environment on Pigmentation*

The development of protective coloration is well exemplified among fishes, just as it is among terrestrial animals. Pelagic fish, and deep-sea fish which swim in the upper water layers, tend to have dark greenish, reddish-brown, or bluish coloration on the dorsal surface, and to be more or less silvery on the under surface. Thus some protection is afforded from predators, which view their prey against a dark or a light background from above and from below respectively. Many fish have the faculty of rapidly altering their colour pattern to match that of the environment. This has been shown experimentally in the aquarium by placing a Mediterranean flat-fish on a succession of substrates of different patterns. The fish rapidly assumed the patterns in succession to such a degree as to merge into the background and be quite inconspicuous. In the course of an extensive research cruise from Scotland to Iceland, via the Faroe Islands, I have had the opportunity of observing the range of variation in coloration of cod captured in different localities. During that cruise the cod taken varied from the ordinary reddish-brown of the so-called rock cod of the red and brown seaweed zones close inshore, to various darker tints in cod taken in deeper offshore waters, and so on to the yellow biscuit-like colour of cod captured on Faroe Bank, where the substratum consists of yellowish shell fragments, and to the black cod caught off the coast of Iceland in the vicinity of the volcano, Mount Heckla, where the sea-floor is covered with black gravel derived from the volcano, and from lava blocks which have been broken down by wave attrition. Here, also, other fish such as soles, plaice, haddock, halibut, and flounders are black, though this is not their normal colour elsewhere. Albino cod were also taken during the cruise. Obviously, in the face of such variation, little reliability can be placed on coloration as a criterion in establishing some fish species.

2. *Effect of Temperature*.

Variations in the average water-temperature conditions in which fish live do, however, have definite and recognisable effects. We have already seen that relatively few species, often prolific in numbers, have succeeded in colonising the colder waters.

We may again select the typical fish, the cod, as our example. It is essentially a cold-water fish—I have found it to occur quite plentifully off Labrador and on the Newfoundland Banks at temperatures around 1° Centigrade below zero, and it occurs commonly at temperatures below 7° Centigrade. On the east North American coast it occurs from Labrador, where the temperatures are around zero and the growing season is correspondingly short, southwards to the New England coast, where temperatures are considerably higher. McKenzie (1934), has shown in aquarium tests that cod will feed and live in water up to a temperature of about 19° Centigrade.

From a study of the vertebrae and the scales of cod over most of the above region, I was able to deduce that the entire cod population could be split into what may be termed races, each exhibiting certain definable characteristics according to the zone occupied in the total north-east to south-west distribution. There was, for example, a fall from around 55 vertebrae per fish on the cold Labrador coast to about 53 in warmer waters influenced by the Gulf Stream (Thompson, 1943). Similarly, for the East Atlantic, Schmidt (1930) has found a decrease from about 54 vertebrae in the colder northern waters to about 51½ vertebrae in the warmer southern waters. These are, of course, average figures.

A somewhat parallel effect of temperature can be traced from a comprehensive study of the scales of the cod. Under magnification the scales show what may be called annual zones, each containing a number of circular ridges, which we will call circuli. This is shown clearly in colder waters (Plate I, fig. *a*), where there is a long winter break in growth, and less clearly in warmer waters, where growth is more continuous. Counting the circuli in the first year zone of scales taken over a great range, I found that the average number varied from eight in the cold (Labrador) northern waters to about 20 in the warmer (Nantucket) southern waters. We may also see the imprint of the varying environmental conditions of this region in the scales of the salmon. Along with a co-worker (Lindsay & Thompson, 1932), I found that the average number of years spent by salmon in the parr stage in rivers, before entering the smolt stage and migrating to sea, varied from two in the warmer rivers of the south-west to six (with one case of seven) in the colder rivers of the north-east. Obviously, it takes much longer for salmon parr in the short summer of the cold north to attain a size at which migration to sea can be essayed.

In the large Australian area, where there is a wide range of water temperatures, we naturally find different species of fish acclimated to different regions. For example, several species of eels, each with its specific habitat, have been shown to occur, each in a more or less circumscribed region.

In the case of birds, it is common to find that migrations occur between warm feeding and cool breeding climes. Somewhat similar movements can be discerned in, for example, the case of the North Sea haddock, which has been shown (Thompson, 1927) to carry out annual migrations from northerly spawning to more southerly feeding grounds, the net average migration being over a space of about 2° in latitude.

It would appear that temperature requirements are fairly specific for spawning, whereas fish will spread out and feed over a much wider temperature range.

It is noteworthy that cod eggs, held in water of zero temperature, hatch with difficulty, and only 50 per cent of them develop at all, taking 40 days in the process, whereas at 9° C. hatching occurs in nine days.

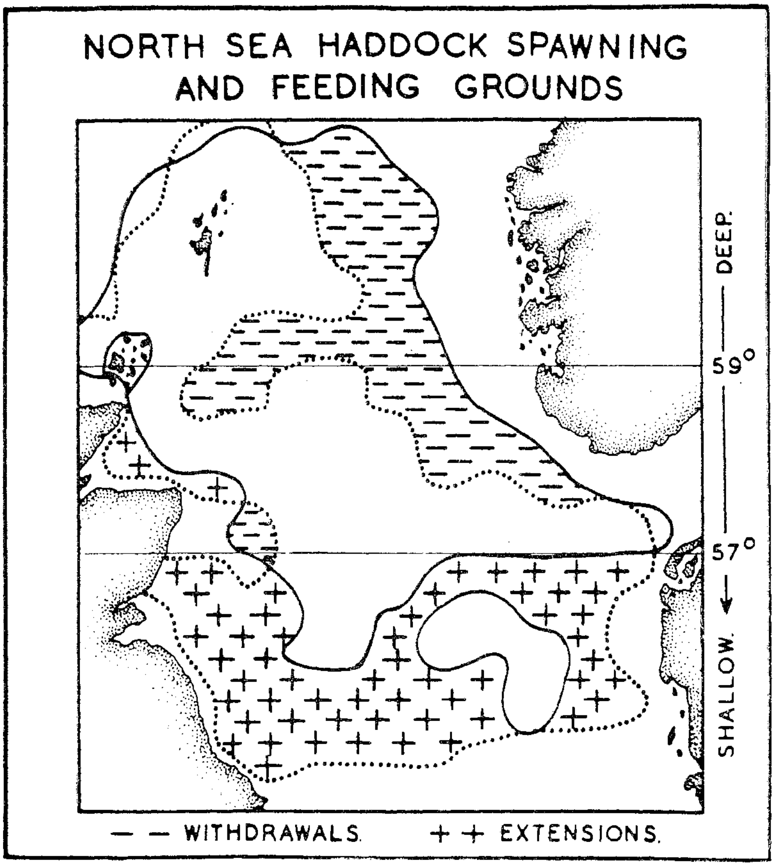

FIG. 1.—North Sea Haddock.
Limits of main spawning grounds—Fulcrum at approx. 59°N. Lat. Limits of main feeding grounds—Fulcrum at approx. 57°N. Lat.
In general, spawning takes place in the deeper northern waters.

In the warmer Australian waters hatching of fish and shellfish eggs takes place very rapidly. This would appear to be a favourable factor and should, in particular, aid in cultural experiments, some of which are about to be attempted.

Thus it is intended to attempt to introduce the Pacific oyster *(O. gigas)* from Japanese to Tasmanian waters. It has hitherto been introduced to east Pacific waters with considerable success, but the lower water temperatures there have hindered successful spawning. The difficulty has been got over to some extent by suspending the oysters in floats where the water could attain a higher temperature. Similarly, it is intended to experiment with the artificial culture of the pearl-shell oyster in tropical Australian waters.

Transplantation of fish to neighbouring but better feeding areas has been successfully accomplished. For example, plaice have been transferred from the coastal waters of the North Sea to the Dogger Bank, where water temperatures are higher and there is plentiful food. The result was an increase in growth rate. However, as was indicated above, transplantation to entirely new regions is often a matter of great difficulty. For example, attempts to introduce herring and lobsters to New Zealand waters have failed. Better results appear to be attending current experiments to transfer lobsters from the West Atlantic to British Columbian waters (Pacific Fisherman, August, 1947).

Sudden temperature changes of any considerable extent are lethal, as are extremely low or high temperatures. For example, the past winter was a very severe one in the North Sea, temperatures as low as 1·7° C. at the surface, and minus 1° C. at the bottom, being recorded. Observations are to be made on the effect of these low temperatures on the plaice. When extremely cold winters have occurred in the southern North Sea in the past, large numbers of fish have succumbed, since the water is shallow and fish cannot have recourse to deep water which might be of higher temperature. Even in the case of Newfoundland cod, which are acclimated to very low water temperatures, sudden changes in temperature may be lethal. Such changes can occur when cold Arctic water floods a slightly warmer area. The cod are at times killed and float to the surface. Thus I have related (Thompson, 1943) an instance where a vessel, in the Gulf of St. Lawrence, steamed through 20 miles of sea where dead codfish, floating at the surface, were observed.

Instances are even known of cod having been driven by seals from deep water to very cold surface water, where the fish were paralysed by the cold, and killed.

It seems certain that the cod is sensitive to very slight temperature changes. During experimental fishing on the Grand Bank of Newfoundland, I found that in a given locality the fish were consistently aggregated in water of a certain temperature, and that in a nearby locality, where the water temperature was less than a degree higher, they were consistently absent. In general, cod were found at spots where lower temperatures prevailed, and haddock in neighbouring localities where temperatures were a very few degrees higher. Bull (1936) has shown experimentally that cod are sensitive to a change of temperature of less than one-tenth of a degree, thus confirming a finding in the field and carrying it to a finer degree of precision by aquarium tests.

Enough has been said to show the very great influence of temperature on the welfare of fish. In Australian waters sudden changes of water temperature are less in evidence, at least in the lower temperature ranges. Where fish welfare is affected and mortality is caused by extreme temperatures it is usually due to high summer heating of limited bodies of water—particularly bodies of fresh or brackish water. Death in such cases may, however, be due to deoxygenation of the water through putrefaction of plant and other life which has succumbed.

3. *Effect of Salinity*

Little need be said on the subject of the effect of water-salinity on fish. It is well-known that fish in general are divided into fresh- and salt-water species respectively, although certain fish, such as salmon, mullet, and eels, spend different phases of their life in fresh and salt water respectively. As in the case of temperature, however, sudden and extensive changes of salinity are lethal. Such changes can, for example, take place at river mouths in the case of the occurrence of floods, with severe effect on shellfish, such as mussels and oysters. It is, of course, customary for sea-running trout, as a defensive measure, to accustom themselves very gradually to the change-over from fresh to salt water, thus avoiding abrupt changes in salinity.

THE IMPORTANT ROLE OF NUTRIENT CHEMICAL CONSTITUENTS OF WATER

Production of food in the form of fish flesh depends ultimately on the availability in the water of nutrient salts, such as phosphates and nitrates, just as crop production on land depends on similar nutrients in the soil. In the sea, when temperatures begin to rise in spring, there is, in the upper or phototropic zone, an outburst of microscopic plant life or microvegetation, production of which goes on until the nutrient salts are used up. This vernal outburst of plant growth provides food for minute marine organisms, which in turn form the food of the small larvae and fry resulting from the hatch out of fish eggs. These tiny fish are part of the food of larger fish, which at this period of the year feed well and

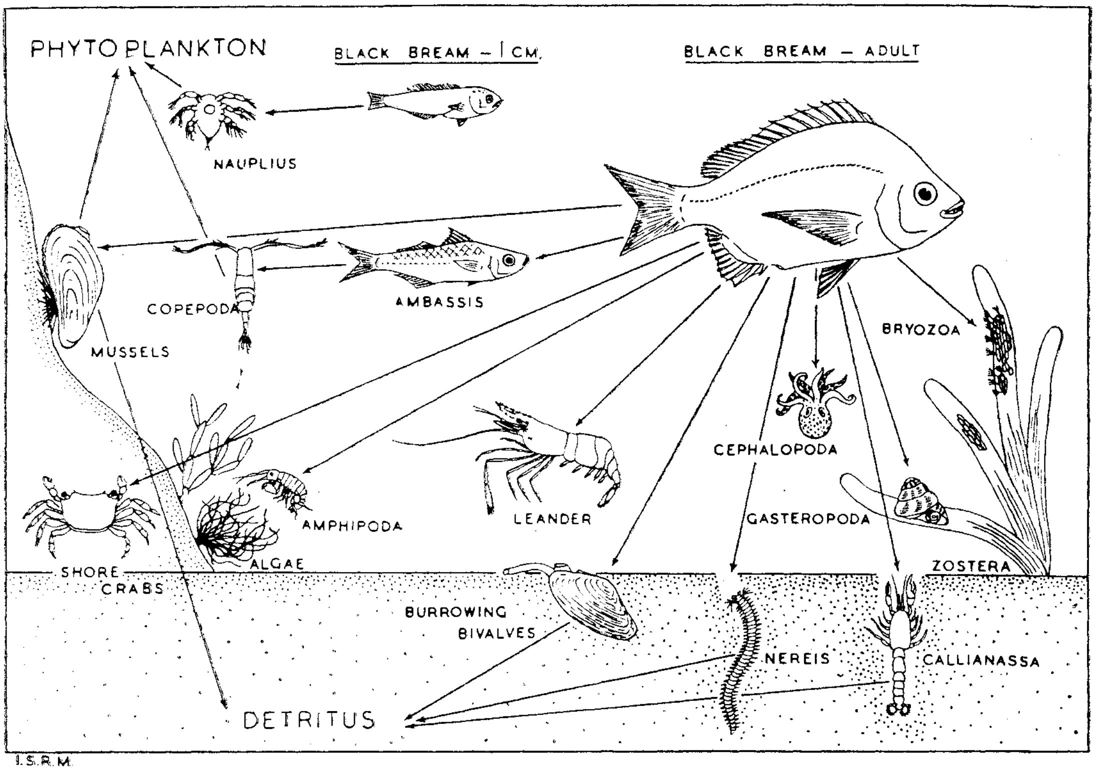

FIG. 2.—Diagram illustrating the food cycle, culminating in the organisms fed on by the Black Bream (after I.S.R. Munro).

increase in size. In tropical and sub-tropical waters where there is pronounced stratification of water layers—with the warm water normally on top—salts are exhausted after a very few weeks or months, and the outburst of growth of microscopic plankton dies out. It is during this period that fish, e.g., mullet, put on most of their year's growth. In certain localities, however, there may be more or less continuous re-introduction of nutrient salts to the surface waters through the mixing of nutrient-rich waters from deeper layers by favourable currents or swirls. Particularly is this the case where persistent cold currents flow in from high latitudes and cause mixing. As an example of this phenomenon the Humbolt Current, flowing up the western coast of South America, may be mentioned. This region is renowned for its high production of plankton, which supports a great sea-bird population, which has given rise to the great guano deposits of Chile and Peru. This cold current normally dominates the situation, but, to quote the words of D'Arcy Thompson (1937) 'now and then persistent northerly winds check it or thrust it aside. Then comes el Nino, a new warm current upsetting the old equilibrium; the fish die in millions, the water stinks, the birds starve, the guano industry cries aloud'.

To the south of Australasia there is a kindred movement of water, containing a certain admixture of cold Antarctic water, which, while it reaches the South Island of New Zealand, keeps well to the south of the southern coast of Australia. Even Tasmanian waters, the coolest of the Australian seas, do not receive this Antarctic water component, nor do they contain typical Antarctic organisms in the plankton. It should be mentioned that one method of determining the source or sources of water masses is to study the types of the organisms in the plankton. I have made an intensive study of the Tunicates in the plankton of the south-eastern Australian region (Thompson, 1942) and have found tropical and sub-tropical species to be present in great numbers, but have not detected the occurrence of any one of the very few species which occur in the Antarctic.

In the cold water of high latitudes there is much greater upwelling of deeper water, with copious phosphate and nitrate content. This movement occurs owing to the action of the currents, and mixing is also caused by convection which occurs when sharply cooled water descends in winter owing to its greater density. In the warmer parts of the ocean this mixing by convection is much less prevalent, the tendency being towards stratification of water layers, with the warmest water remaining near the surface.

In general, therefore, it is not surprising that phosphate values are high in Antarctic waters, and comparatively low in tropical and sub-tropical waters. These values can be expressed as units denoting parts of P_2O_5 per cubic metre (or one million cubic centimetres) of water. Values of from 50 to 100 units occur in Antarctic seas, and values of around 15 in Australian waters. It is therefore not surprising that plankton production appears to be greater in colder than in warmer seas, and that Jespersen (1935) found that, as far as his investigations went in the Tasman Sea, the relationship between the amount of plankton taken with a stramin net was reciprocal with water temperature. In a passage from east to west across the Tasman Sea he found rising temperatures between New Zealand and Australia. As the water temperature increased, so did the volume of plankton, obtained by a standard technique, fall.

Since total fish production is dependent, in the ultimate issue, on total plankton production, the colder waters of the world naturally produce the heaviest and most consistent fish catches. This appears to be due to the greater and more prolonged availability of nutrient salts and not essentially to lower temperature itself, since, as I shall now show, low temperature alone does not necessarily produce fastest growth in any particular species such as haddock, cod, or salmon. Indeed, the artificial introduction of nutrient salts to warmer waters can lead to very fast growth of fish. Thus, I am informed by Mr. Dunbavin Butcher that in Lakes Parrumbete and Coleraine in Western Victoria, Australia, the growth rate of introduced Quinnat salmon is very fast indeed. These lakes receive drainage from a rich agricultural hinterland, and hence are well supplied with nutritive salts. This suggests a task for the research worker—to show to what extent the productivity of rivers, lakes and ponds, and, possibly, of suitable estuaries, can be increased by the controlled addition of fertiliser or of superphosphate or other nutrient salts.

Variation in Growth Rates, e.g., of Haddock, Cod, and Salmon

My own first assignment in the field of fishery research was to a study of the haddock of the North Sea. This was in 1921. At that time there was considerable controversy as to the value of fish scales in indicating age. Hoffbauer (1898) had shown that, in carp, the scales showed annual rings. The position was, however, that proof had to be produced, species by species, that annual zones could be recognised on the fish scale. As I will show later, it was possible to produce this proof in the instance of most haddock, and it has been possible to do so also for many other fish species. But some species have proved troublesome. Thus the cod scale, except (Plate I, fig. *a*) in regions where there is a sharp difference between summer and winter temperatures, is not easily interpreted. Another prolific fish, the common herring of commerce, has been the subject of much controversy on this score, attempts having been made to prove that the numbers of apparent zones on the scales could be explained according to the laws of chance. Intensive research, which has indicated among other things that in the North Sea there are spring and autumn spawning seasons, has explained away most of the anomalies, and critics of the acceptance of the scale-age theory for herring have now been won round to the acceptance of this theory. In the case of haddock, the position was that whilst Norwegian workers claimed the age could be read with certainty from the scales, English workers had found at least a proportion of the scales unsatisfactory for age-determination owing to extra markings. There is sometimes one such extra ring found during the first year, when haddock change over from mid-water to bottom feeding conditions. I have also shown (Thompson, 1926) that, in transferring haddock from sea to the aquarium, the change in conditions can cause an extra ring to be formed. The position to-day is that most workers use the scales in the case of younger haddock, but that in regions such as Iceland waters, where many older haddock occur, otoliths are used as giving a clearer indication of age than do scales.

Within two or three years of commencing studies on haddock scales, I was impressed with two indications—the first of which was that fish of the same age attain different sizes in different regions. Thus there is gradation from the deep waters of the northern North Sea—where low temperature and scanty food supply (even *Foraminifera* are resorted to as food) restrict growth, and where a large size could never be attained—through the more genial conditions of shallower banks (e.g., Dogger Bank) and of inshore waters, to the regions of fastest growth, where food is most plentiful. Such regions are the west Scottish coast, subject to Atlantic conditions and, further afield, Faroe, Iceland, and the west Atlantic from Grand Bank, Newfoundland, to Brown's Bank, Massachusetts.

A region of fast growth will obviously, by providing fast recuperation, sustain a more intensive fishery than will one of slow growth. It is therefore of fundamental importance in fishery investigations to study rates of growth. Prior to the institution of current investigations, this had not been done in Australia. In recent years the growth rates of mullet, bream (Plate II), pilchard, &c., have been determined, and this work is proceeding with respect to other fish such as salmon, tuna, barracouta, and trawled fish such as flathead. In the latter case—the flathead—the tiny ear bones (otoliths) are being used (Plate III). Even in the case of the scallop—a shellfish—it is being found possible to make use, in general biological studies, of the periodic markings on the shell (Plate I, fig. *b*).

Fluctuations in Fish Stocks

The second indication that impressed me was that the year classes were not equally represented in the total haddock population. It soon became clear that the survival rates from successive spawning seasons varied, sometimes very greatly (Thompson, 1922). Norwegian workers had previously shown that in the case of the herring one year class could be born and survive in such great quantities as to form the major part of the catches for a series of years. In the case of haddock something similar was soon shown to occur. The year classes of 1920 and 1923 were, in succession, dominant, and those of the intervening years 1921 and 1922 almost complete failures. I found it difficult to convince some of my colleagues of the truth of this at the time—so much so that in 1922 extra cruises were organised to scour the North Sea for the baby haddock which, it was assumed, should be present, but which had not shown up in any numbers in the catches of the experimental trawler. At this time interest in the position of the haddock fishery was stimulated. We had seen an increase in the haddock stocks, occasioned by the rest period—one of recuperation—enjoyed by the stocks during World War I, when, as during the recent war, fishing activities were greatly reduced in the North Sea. In 1919, the year following the war, large haddock were four times as plentiful as they had been in 1913, the year before the war. A rapid sequence of events followed—the resumption of the fishery, which rapidly reduced the haddock stocks to a much lower level, and the failure of two successive year broods—those of 1921 and 1922, which further reduced fishery returns to an unprecedentedly low and unremunerative level—so that it was commonly thought in the trade that the fishery was finished with, at least for the time being. I therefore published a forecast in these words 'The 1920 brood in 1923 and 1924 should allow the haddock fisheries to recover from their present depression. Should this prove to be true, the scale theory, as far as the formation of one ring per year goes, should, in the main, be established for the haddock'. As was anticipated, catches turned upwards in 1923. The 1920 brood was being caught at commercial size, and formed 70 per cent of the total haddock catch in 1923. Furthermore, whereas in 1922 little trace could be found of baby haddock, in 1923 the research vessel found them in prolific numbers over most of the northern region, and it was possible (Thompson, 1923) to predict the further recovery of the haddock fishery in 1924 and 1925, when the 1923 fish would have attained marketable size. From that time, through a sustained study of the relative degree of success of successive year broods, a prediction system for North Sea haddock was maintained.

In more recent years forecasts have come to be made with regard to other fish whose biology has been intensively studied. Thus Hickling (1946) states that in any one year the abundance of small hake likely to occur to the south and south-west of Ireland can be forecast five years in advance, if the temperature of the sea surface in that year is known. A high temperature at the surface means a high survival rate of newly born hake. In the case of haddock the causes of good and bad survival rates are not known. They might include absence of suitable food supply for the myriads of young fry, or even the carrying by adverse currents of the eggs or early pelagic stages into regions where conditions for further development are unsuitable.

The study of growth rates and the study of fluctuations may therefore be bracketed together as being of fundamental importance to commercial fisheries. Examples have been drawn above from authenticated cases in large fisheries studied over a period of years. In Australia similar studies are now in progress and already we see signs of useful results. An instance (flathead fluctuation) will be mentioned below.

The Influence of Man on Aquatic Life

Yonge (1947) states that man had little direct influence on marine life till about two hundred years ago, when there began a vast and indiscriminate slaughter, leading to the extermination of some species—for example the Northern Sea-Cow in the north Pacific. Another member of the sea-cow group (Sirenia)—the dugong of Indo-Pacific Seas—still survives, but requires protection. The population of whales in Arctic regions has been reduced to very meagre numbers, and that of the Antarctic, upon which the modern highly mechanised whaling industry is based, has also suffered great diminution and is receiving a measure of protection. Ommanney (1938), commenting on the position with regard to the elephant seal, states that at South Georgia, where killing is restricted to old bulls, numbers are being maintained, whereas on other islands where no regulatory measures have been adopted, this seal is dying out. It is the function of scientific investigations, such as those carried out so successfully by the 'Discovery' expeditions between the two world wars, to secure the necessary fundamental biological information upon which to base measures of conservation or, to use the words of D'Arcy Thompson (1937) 'to tell the commercial world how far greed might safely go'.

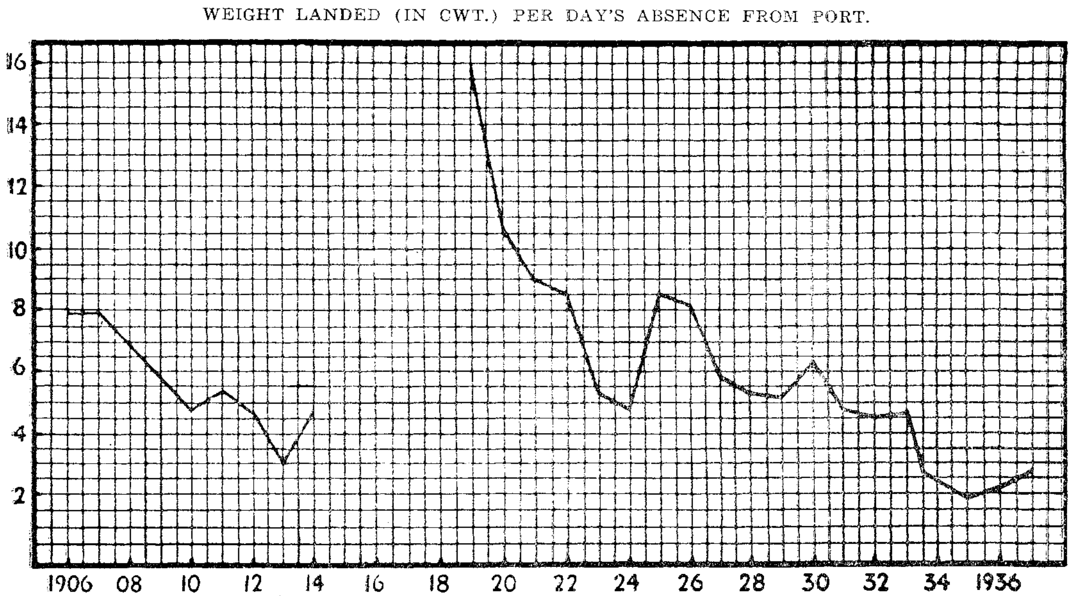

FIG. 3.—Graph showing weight (in cwt.) of haddock landed per day's absence by English steam trawlers in the North Sea.
Declines are shown prior to both world wars, but a considerable recovery is evident in 1919, subsequent to the recuperative period of 1914-1918. (Data from Russell, 1942.)

The scientific study of fish populations has usually been introduced long after the fishery has been taking its toll and has reduced the stocks. It is therefore impossible to say exactly how great these stocks were in their pristine condition. The occurrence of two wars within a generation has, however, through providing a partial closure of certain areas to fishing, given us some idea of how far depletion can go and how extensive the recovery can be in certain cases at least. Dr. E. S. Russell (1942) says that the average landings of haddock in hundredweights, per days' fishing, by English steam trawlers was 7·8 in 1906. By 1914, at the beginning of the war, it had dropped to 4·6, but it recovered to 15·8 in 1919, at the conclusion of the war. However, by 1937, it had receded to a new low of 2·7—a desperate situation. Here we see unmistakable evidence of a fall due to increased fishing intensity up till 1914, a very marked recovery by the end of the war, and a subsequent and still more pronounced drop up to 1937. From a report (1946) on the sea-fisheries of England and Wales for the years 1939-1944 inclusive, we learn that the North Sea was closed throughout World War II, except for a belt down the east coast varying from 15 to 30 miles wide. The landings of demersal fish fell in 1940 to 31 per cent of the 1938 figures, and still further to 24 per cent in 1941, afterwards rising slightly. The report says that there has been in several areas a marked increase in the weight of fish on the grounds, due to the decrease in the intensity of fishing, this increase being of the order of from 250 to 400 per cent, according to area, and as measured by catch per unit of fishing effort. Besides being more numerous, the fish were larger than before the war. Here is a statement taken from this report: 'It is common knowledge that after the 1914-1918

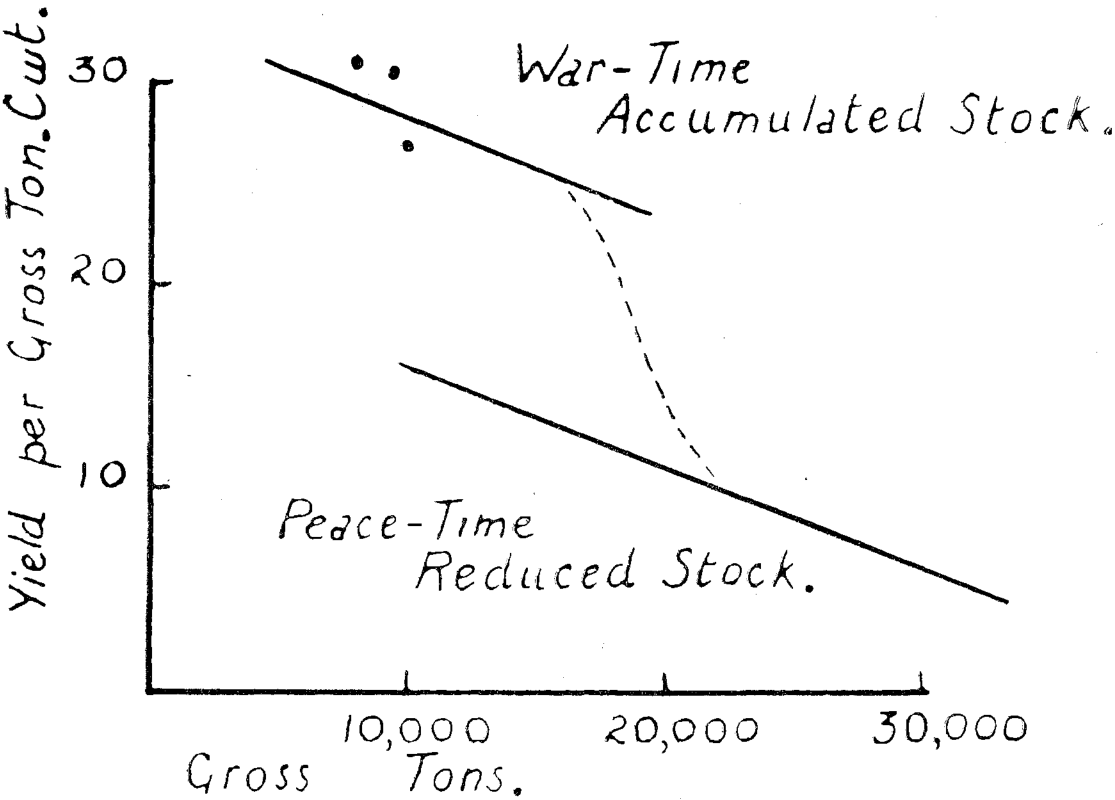

FIG. 4.—Transition from a 'war-time accumulated stock' of hake (in south-west British area) to a 'peace-time reduced stock', with increase in the size of the trawling fleet. The relation between the size of the fleet, in aggregate gross tons, and the yield of hake per gross ton, in the years 1920 to 1938, is shown as the regression line marked 'peace-time reduced stock'. The regression line shows that, the larger the fleet, the smaller the yield of hake to each unit of the fleet. A second regression line, parallel with the first and marked 'war-time accumulated stock', is drawn through the points representing the yield per gross ton in 1942, 1943, and 1944. (From Hickling, 1946.)

war there was an uncontrolled scramble . . . to send trawlers and other fishing vessels to those fishing grounds which had been closed for the duration of the war, without any regard to the consequences. For a year or two large landings and high prices resulted, but the inevitable slump followed and fishing became uneconomic. By the time the World War was in sight most of the British vessels working this area were working at a loss . . . . The North Sea had, in fact, been overfished, and the same was true of other areas. So many fish had been taken out that the remaining stocks could not maintain themselves'. Hickling (1946, 1946*a*) also states that since 1939 there was a spectacular improvement in the catch of fish per unit of fishing effort on Porcupine Bank, off the west coast of Ireland. The increase extended to many fish species and varied from 50 per cent in the case of small to 200 per cent in the case of large trawlers. With regard to hake, he states that the rate of reduction of stocks fell from 46 per cent per annum before the war to 21 per cent during the war. Consequently, from 1942 to 1944 a fleet reduced to 8000-9000 tons landed more hake than a previous fleet of 20,000-29,000 tons. In 1945 a fleet of less than 10,000 tons caught two-and-a-half times the amount caught in 1932 by a fleet three times as large.

However, Hickling, who recently visited Sydney, has informed me that North Sea catches have already fallen by about 50 per cent from the high level of the immediate post-war period. With regard to hake, which is fished chiefly on the western fringe of Ireland and Scotland, and hence mostly outside the North Sea, he shows the transition from the war-time accumulated stock to a peace-time reduced stock, occasioned by the increase in the size of the trawling fleet. For the period 1920-1938 he draws a regression line (the upper line in the accompanying diagram) showing that, the larger the fleet, the smaller was the yield per unit of effort expended. For the period 1942-1944 similar regression line has been drawn through points indicating yields per gross ton employed in the fishing fleet.

Other fish stocks now show similar war-time and inter-war-time trends. Thus G. A. Stevens (1947) states: 'Before the outbreak of the 1914-18 war and for a few years after its close the Cornish long-line fleet, working from Newlyn, used on an average to work from 1000 to 1500 hooks per vessel on from 2½ to 3 miles of line. Gradually they became obliged to use from 2000 to 4000 hooks on from 5 to 7 miles of line in order to catch the same amount of fish, or rather less. Moreover, instead of fishing as a rule within a radius of 50 miles from the port they had to operate on grounds up to 90 or even 100 miles distant. In due course no further increase in the amount of gear that could be used from the existing vessels could be made. The extreme limit of their range was also reached, and the catches continued to fall . . . . But war came and the grounds were rested, and catches were good once more'. The fishery referred to the elasmobranchs, or gristly fishes, the rays and skates, and we see a somewhat parallel state of affairs in the south-eastern Australian fishery for another elasmobranch fish, the school shark. This fishery received an impetus during the war on account of the need for liver oils rich in vitamin A, and Victorian fishermen have found it necessary to go further and further afield for good supplies.

Similarly, with regard to some crayfish grounds, the areas covered by fishermen in order to secure an economic catch is steadily increasing. In New Zealand and South Africa there has been little recovery in some areas where stocks of crayfish have previously been reduced to low limits.

With regard to the important trawling industry of New South Wales, investigations have been and are being made on the level of the more important fish stocks. The peak in this fishery was reached in 1929, when 15 million lb. were taken by 17 trawlers. There was a subsequent drop to a low of 10 million lb.

in 1935, but a reduction in the number of trawlers to 13 enabled the stocks to recover and a steady return of about 12 million lb. by 13 vessels can apparently be sustained. There was marked over-fishing from about 1928 to 1935. In the earlier days (1918-1926) this fishery produced from 5-7 cwts. of fish per trawling hour, compared with 2-2½ cwts. in the period 1930-1940. There was a phenomenal increase in the smaller (Danish seine type) trawlers in the late war and in the post-war years, so that in 1946-1947 there was a total fishing effort from a fleet of about 4600 trawler tons, compared with 4000 trawler tons in 1929. At present there is a fishing potential of over 5000 trawler tons, whereas a figure of about 3500 appears to be the maximum required if stability of fishing results is to be maintained.

There is no evidence of any very remarkable increase in stocks (on North Sea standards) during the war. The position is that the average catch of tiger flathead—the chief trawled fish—has dropped quite considerably since the war, and this decrease in flathead has directed more attention to the taking of other varieties of fish, such as morwong. It should be mentioned that Tasmania is interested in the trawl fishery to a more limited extent, the research seine trawler 'Liawenee' having from time to time made good catches off the east coast of the island.

Obviously, while it is certain that Australian fishery resources are far from fully utilised, there is a distinct need for careful management in some instances. This is necessary if the maximum return is to be achieved over an indefinite period, as it can be. A limit must be placed to the degree of exploitation in the case of most fish species (an apparent exception being the prolific herring in the North Atlantic). There is a limit to the number of new grounds which can be turned to, and the hatching and turning into the sea of fish fry has never been proved to be beneficial. Useful measures which can be taken, once sufficient basic data have been accumulated to suggest what they should be, may include the avoidance of the capture of a great proportion of what are termed undersized fish, whether by increasing the size of the meshes of nets, or by instituting minimum size limits of fish to be marketed; protection of spawning fish or spawning grounds; and limitation of the total permissible catch. One or two examples may be cited.

In 1935 W. C. Herrington, after investigating the alarming decline in the catches of haddock on the once prolific George's Bank off the east coast of the United States, drew attention to the effect of using in the cod-end of the commerical trawl a mesh of only 3 inches. He indicated that trawlers once destroyed 63 million baby haddock in one season and advocated a 4¾-inch mesh in the cod-end. His experiments, carried out on a commercial scale, showed that four-fifths of these brood haddocks could be allowed to escape without reducing the amount of marketable fish captured. At the 1935 meeting of the North American Council on Fisheries Investigations, at which I was present, an international treaty was favoured to protect the fisheries of all banks. Nothing however was done. In the fisheries journal 'The Atlantic Fisherman', of January, 1947, it is stated that the Atlantic Fishermen's Union drew up, in 1942, a bill to be introduced to Congress, limiting the size of fish to be marketed and restricting fishing during the spawning season, but no one would sponsor the bill in Congress. The journal goes on to state that fishermen are now finding it necessary to go further from the home port.

It is of interest to note that similar experimental work in the North Sea has shown that an increase of mesh would spare a proportion of young fish without reducing the marketable catch. Since it was known that the fishing grounds of western Europe were again well stocked after the war, the British Government called an international conference in London in 1946 to discuss the over-fishing problem. It was agreed to increase the mesh size of nets, and also to set a size limit on 12 of the most important demersal ground fish. An advisory committee was also appointed to give special attention to the matter.

In the case of the Australian flathead it is now proposed to test the effect of using a 3½-inch, instead of the existing 3-inch, mesh in the cod-end of nets used by trawlers, the object being to allow a considerable proportion of small and unsaleable fish to escape Thus it should prove helpful if the small two-year flathead were allowed to escape and grow to a larger size. But quite apart from this conservative measure, it may also prove to be necessary to restrict the total tonnage of the fishing fleet, or to protect spawning fish.

In the case of the Pacific halibut, a sharp decline in stocks has been checked and the downward trend reversed—in this case, not by the intervention of a war period, but by the application of conservative measures based on scientific evidence. Through treaties subscribed to in 1924 and 1930, and renewed in 1937, by Canada and the United States, limits were set to the quantities of halibut to be taken, and certain important spawning grounds were protected. The halibut population has, as a result, greatly increased and the fishery has been rescued from its state of reduction to an uneconomic level. Here, as elsewhere, it has been abundantly shown that, paradoxical as it might appear, a greater quantity of fish can, in the case of some fish stocks at least, be taken by reducing the actual fishing effort.

Aids to the Fisheries from Research

The increasing tendency towards management of the fisheries on a scientific basis has manifested itself during the period between the two world wars. As in the case of forest management, it has come to be realised that only the natural increase can safely be removed.

During this period, scientific investigations have laid bare, or emphasized, certain truths of first-class importance. Let us recapitulate some of the chief of them.

1. Fundamentally, productivity in the sea, as on land, depends on the *availability of nutritive salts* such as phosphates and nitrates. The action of light rays, which penetrate to a depth of about 200 metres, creates a plant life upon which a herbivorous fauna grazes, this fauna being, in turn, utilised by animal life up the nutritive chain. The normal colour of water is azure blue, on account of its ability to absorb red rays. On fishing banks, such as the Newfoundland banks, the colour is green on account of abundance of microscopic plant life (diatoms, etc.), aided by matter in suspension. On banks, and in cold water generally, the supply of nutritive salts tends to be regenerated by mixing caused by water movements (upwellings, eddies, convection, etc.) after the supply of nutritive salts has been exhausted, as they tend everywhere to be by the outburst of growth ('flowering') each spring when temperatures begin to rise. Thus, as D'Arcy Thompson (1937) states, a vast abundance of life strikes every naturalist in Arctic or Antarctic seas, the coldest of Antarctic waters being the richest in the world. Commenting on the results of the investigations of the 'Discovery' expeditions, he states that the gathering places of the whales may be expressed in terms of plankton (e.g., the big shrimp-like *Euphausia superba* which is the staple food of the blue whale) and also of the phosphate supply.

   A systematic survey of the availability of nutritive salts in Australian waters, which are tropical and sub-tropical, is proceeding. The general level is not high, although there are exceptions where local mixing occurs.

In fresh or in more or less closed waters it may be possible to augment phosphate supplies by artificial addition. This may, for instance, be of interest in the rivers and lakes of Tasmania. These will always provide satisfactory angling for the few, but to provide it for the multitude it will probably be necessary to adopt artificial measures, possibly including feeding under control as practised abroad. For example, at Healing, in North Lincolnshire, near the fishing port of Grimsby, rainbow trout are forced to a weight of about 6 ozs. in a year by being fed each morning in ponds with minced small cod and whiting, which are cheap at the fish market at Grimsby. (Barracouta might similarly be used in Tasmania.) Well over 100 lb. of trout are sold per week, each pound of trout requiring about three pounds of cheap sea food for its production.

It should be noted, however, that plankton is not necessarily uniformly distributed in water where nutrient salt content is uniform. As Lucas (1947) has pointed out, it has been shown in recent years that many organisms appear to require certain substances (e.g., of the nature of enzymes, hormones or vitamins) which they themselves cannot manufacture, and which are not normal foods. These substances may either stimulate or inhibit various biological processes. Thus the presence of some plants, when abundant, may have an inhibitory or even a lethal effect on associated animals, virtually 'excluding' them. This may be due to the effect of external secretions of such plants. Thus 'krill'—and therefore whales which feed on it, have been shown to avoid water of the highest degree of plant productivity. Likewise, Savage and Hardy (1935) have shown that the presence of dense patches of plankton (e.g., certain diatoms) over the normal herring fishing areas of the North Sea can be associated with poorer than average herring catches.

2. A second finding of supreme importance has been that *growth rates* of fish vary quite considerably. Within limits, growth rate is a function chiefly of food supply, and it is desirable to secure a high survival rate in areas where food is abundant. In areas of slow growth, only a restricted fishing intensity can be sustained. Increase of food by adding fertilisers to sea-water is still at the experimental stage, some success having been obtained in limited water masses (Gross, *et al.*, 1946). It is hoped to start preliminary fertilisation experiments in a freshwater area in Tasmania shortly, and such experiments have been instituted in connection with oyster cultivation in George's River, New South Wales. In densely populated regions of Asia, where manurial matter is abundant, large quantities of fish are, of course, produced by fertilisation of ponds, etc.

3. A third outcome of fisheries research during these years has been the production of proof absolute that, owing to natural causes, fish stocks fluctuate in number, the fluctuations being sometimes so violent as to be almost catastrophic in their effect. Perhaps the failure, in two successive years, 1921 and 1922, of North Sea haddock broods has so far provided the most striking demonstration of the disastrously low level to which fish stocks can be reduced when, with stocks already in an over-fished condition, spawning seasons fail to provide reinforcement of numbers.

From the continuous study of *fluctuations* and of the composition of age-groups of the stock, it has been possible to make short-term predictions of the course, not only of the haddock fishery, but of the fisheries based on other species (hake, herring, pilchard, etc.) in various regions. Such *predictions* are of obvious value to those concerned with outfitting for participation in the fishery. Fortunately, in the case of any one species, fluctuations may affect one region more than another—thus the codfishery on the coasts of Norway and Newfoundland may be good now on one part of the coast, now on another; and, since the time of incidence of adverse fluctuations is not necessarily the same in different species, fishing effort can be directed from a species in an unfavourable phase to other species in more favourable phases. It is interesting to note, for example, that of the two great Californian fisheries, that for tuna was in 1946 the most productive on record, and that for pilchard the least productive. Thus those entering on new phases of the Australian fisheries would be well advised to equip their vessels for more than one type of fishing.

4. A fourth major finding in these last twenty-five years has derived from the gigantic, though involuntary, experiments in conservation imposed by the two world wars. It is that of the remarkable capacity for *regeneration* possessed by fish stocks which have been over-fished. After both wars fish taken in areas more or less closed to fishing have proved to be much more plentiful, and to be of a larger average size, than those taken at the commencement of hostilities. This is a heartening consideration, ensuring as it does positive results for such lesser measures of conservation as may be thought to be administratively advisable. The remarkable speed, and the extent, of the reconstitution of fish stocks towards a high level are doubtless largely due to the great fecundity of fishes—a fecundity not shared by marine mammals such as, for example, whales and seals. In the case of whales we know that a very great number of years must of necessity pass before a badly attenuated stock, such as that of the Arctic regions, can effect even a moderate recovery in numbers. In the case of the Bay of Biscay, for example, the Basque harpooners killed out the Atlantic whales, so that no more were seen for nearly 100 years. In the Antarctic, to quote Rudd (1939-41), 'the stock of the blue whales has been reduced to such a degree that the chance of catching a blue whale in 1938-39 was less than half of what it was in 1933-34, in spite of the increase in the efficiency of the boat and the activity of the gunner'. In other words, the stock of whales has fallen below a level which can be balanced by increased fishing activities.

Probable Future Trend in Fishery Research

It is to be anticipated that the tendency towards the application of scientific management to the fisheries will not only continue, but be accelerated, using techniques already to hand, techniques which may well be added to as further discoveries come to light. Thus, while fishing techniques for both pelagic (surface) and demersal (ground) fisheries have been well perfected, much might ensue from the development of methods of taking mid-water fish. Among other results there should accrue some much-needed knowledge of the mid-water phases of the life-histories of such fish as herring and salmon. Particular attention is likely to be given to causative factors in the occurrence of freshwater and marine life. A quarter of a century ago public interest, and that of the industry itself, in research was somewhat apathetic, but occurrences in the interim have quickened that interest. On all hands we see evidence of this. British fisheries research is being extended to cover the prolific, though distant, Arctic grounds, and a large-scale scheme of fisheries research is being planned (and in some cases has commenced) for the Colonial Empire. In the March, 1947, issue of the 'Pacific Fisherman', under the title of 'Tide of Research Rising', we learn of the intention in the United States to expend very large sums in research in its Pacific possessions and the Philippines, and also that the great Californian sardine industry wishes Congress to provide $1,000,000 for research on the sardine stocks which, owing possibly to natural fluctuations, have at times yielded disappointing catches. At the request of member nations, the Food and Agriculture Organisation of the United Nations intends to set up Regional Councils for the stimulation and co-ordination of oceanographic research. One such Council is expected to be established for the Indo-Pacific region, including Australia.

In Australia, the activities of the Fisheries Division of the Council for Scientific and Industrial Research are being intensified with regard to securing the necessary data both for the further development of industries based on the marine resources, and for the rational management of such existing fisheries as are fully exploited.

With regard to the latter, for example, requests have been received from State departments and local authorities for investigations to be conducted into condition of various stocks upon which important fisheries are based, such as the New South Wales trawling industry, the Queensland mackerel, the Tasmanian whitebait and scallop, the school shark, the Tasmanian and other crayfishes, and the freshwater trout of Tasmania.

In Australia, as elsewhere, the prosecution of research is essential if only as a policy of insurance for the maintenance of existing fisheries; and in Australia, where fisheries are only partially developed, the outlay on such a policy must of necessity be increased to ensure expansion on a sound basis. At the same time, the expenditure on research must bear a reasonable relationship to the actual and anticipated commercial returns of the fisheries.

Developmental Possibilities in Australian Waters.

Having seen that some sections of the Australian fisheries have been exploited to the extent that there is already a call for their conservation, let us now comment on other sections, some of which are probably not yet fully exploited, and others of which—particularly those dealing with pelagic fish—stand at the threshold of exploitation subsequent to the carrying out of much exploratory work by aerial reconnaissance and research vessels. Existing fisheries which could sustain expanded effort are, in my opinion, those based on barracouta (the catch of which in Tasmanian waters has risen considerably in recent years, partly owing to the stimulation of war-time regulations—and there are distinct possibilities further afield, e.g., in Western Australian waters); Australian salmon, upon which a canning industry is already based, and the distribution of which, being easily studied from the air, it is proposed to determine with precision; school shark and crayfish, both requiring some aid from conservational measures in Tasmanian waters where they are most heavily fished, but both probably capable of supporting an expanding fishery elsewhere in southern Australian waters; the fisheries of tropical waters in general—including those based on pearls and pearl-shell, in connection with which improved cultural methods are to be tested; the oyster and scallop industries, both of which are now the objects of scientific study; and the sea-weed industry, founded during the war for the production of agar-agar, but, as far as Tasmania, at least, is concerned, capable through the existence of extensive beds of *Macrocystis*, of providing raw material for the production of alginates.

With regard to the development of the pelagic fisheries, we stand at a most interesting stage. The preliminary study of the distribution and seasonal occurrences of the surface fish is now being actively continued beyond the region of south-eastern Australia. In the latter region, including Tasmanian waters, this study has been reasonably well completed, and efforts are now being made to develop the canning industry. On shore there have been installed the necessary cold-storage facilities to accept and hold occasional large catches, which can then be gradually passed through the canneries. The horse mackerel *(Trachurus novae zelandiae)*, since it had, during the appropriate season, frequently been observed to occur in dense shoals in more or less sheltered waters, was thought to be the first species of pelagic fish likely to be taken in quantity by the purse-seine net, and this has proved to be the case. Hauls have been made both in eastern Tasmanian waters and off the coast of New South Wales. So far several catches of around 18 tons each have been secured, and these may be expected to be improved upon with experience. The capture of tuna by purse-seine will also be attempted shortly. This operation calls for the exercise of considerable skill. Hitherto the method of jigging or trolling has been tried out in these waters with, on the whole, unsatisfactory results. The Division of Fisheries of C.S.I.R. is stimulating, and co-operating with, commercial interests and selected fishermen in the testing out of various types of fishing gear used in such work. This work extends beyond mackerel and tuna to smaller fish, such as pilchard, sprats, and anchovies. With regard to these three latter species smaller nets are employed and occasional catches of from a few hundredweights up to five tons have been effected. I think it can now be said with confidence that the development of an industry based on Australian pelagic fish has begun, and that this industry will reach significant proportions as compared with the already existing fishing industry, which is based largely on demersal and estuarine fishes. It is a virtual certainty that Australia, with its large seaboard, will share in a generally increased production from the marine resources of the southern Pacific, which at present yields only a paltry 2 per cent of the fishery products taken from the Pacific Ocean ('Pacific Fisherman', August, 1947).

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PLATE I

FIG. *a*.—Microphotograph of a typical scale from a Newfoundland codfish, showing four completed years of growth.

FIG. *b*.—One valve of the shell of a Tasmanian scallop, showing five apparent annuli and some growth in fifth year.

(Photos. A. Proctor.)

PLATE II

A bream, with a microphotograph of one of its scales showing four completed years of growth. The scale grows in proportion to the fish, and by measuring the annual increments in the scale, the rate of growth of the fish can be determined.

(I.S.R. Munro del. Photo. A. Proctor.)

PLATE III

Microphotographs of otoliths from six flathead:—

1. Length of fish 4 inches. No annulus yet formed in otolith.
2. Length of fish 7 inches. About to form second annulus.
3. Length of fish 11¾ inches. Two complete annuli; third about to form.
4. Length of fish 13¼ inches. Three complete annuli.
5. Length of fish 15¾ inches. Four complete annuli (first indistinct).
6. Length of fish 16¼ inches. Four distinct annuli; fifth just forming.

(Prepared by W. S. Fairbridge. Photo. A. Proctor.)

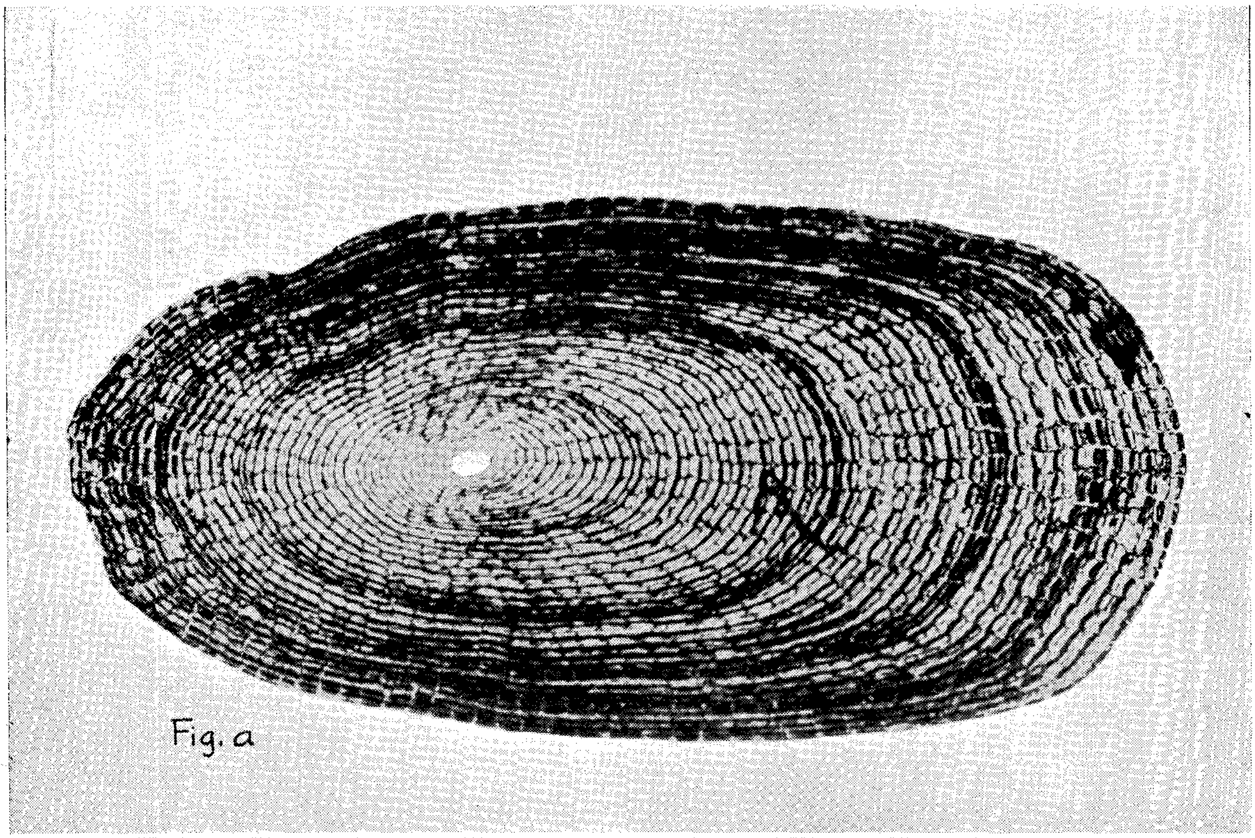


Fig. a

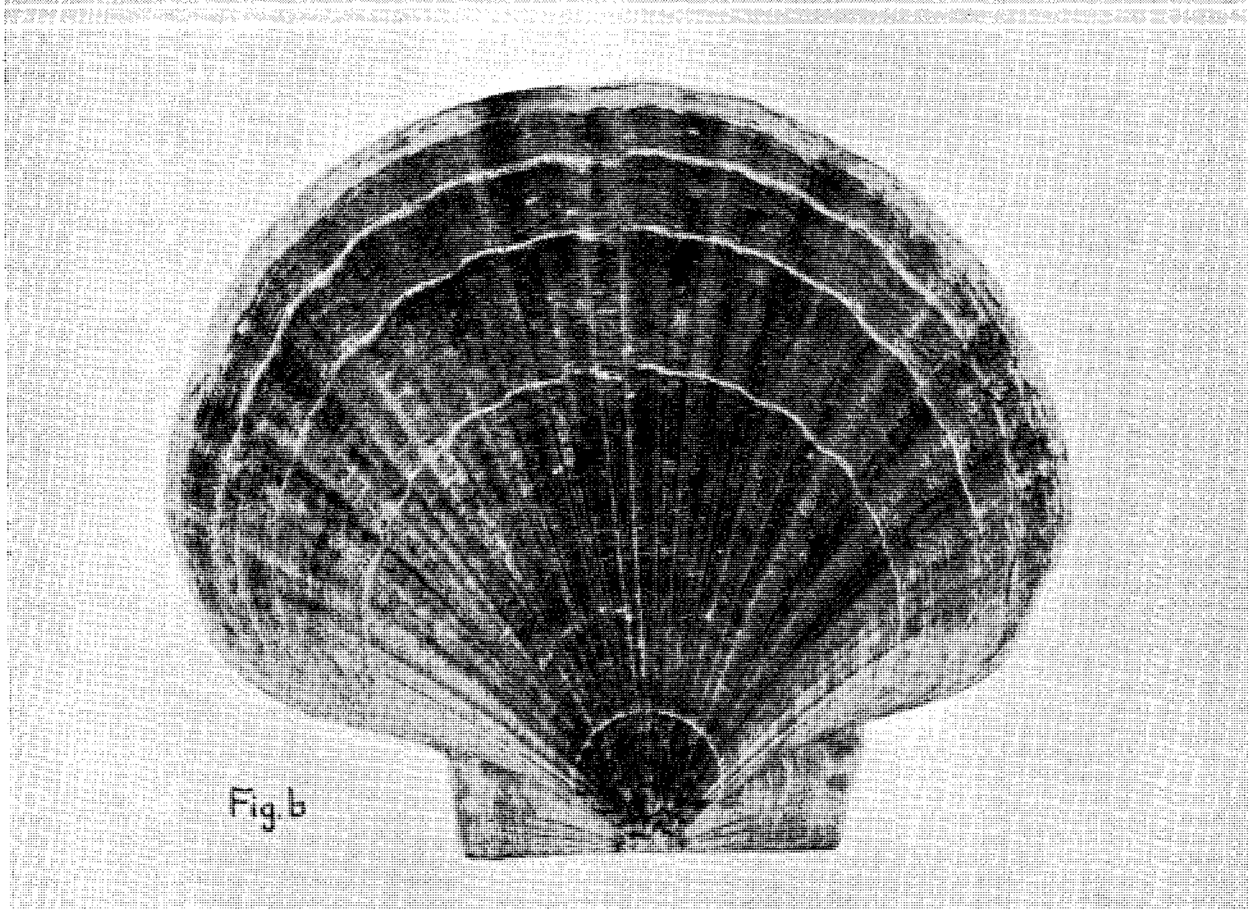
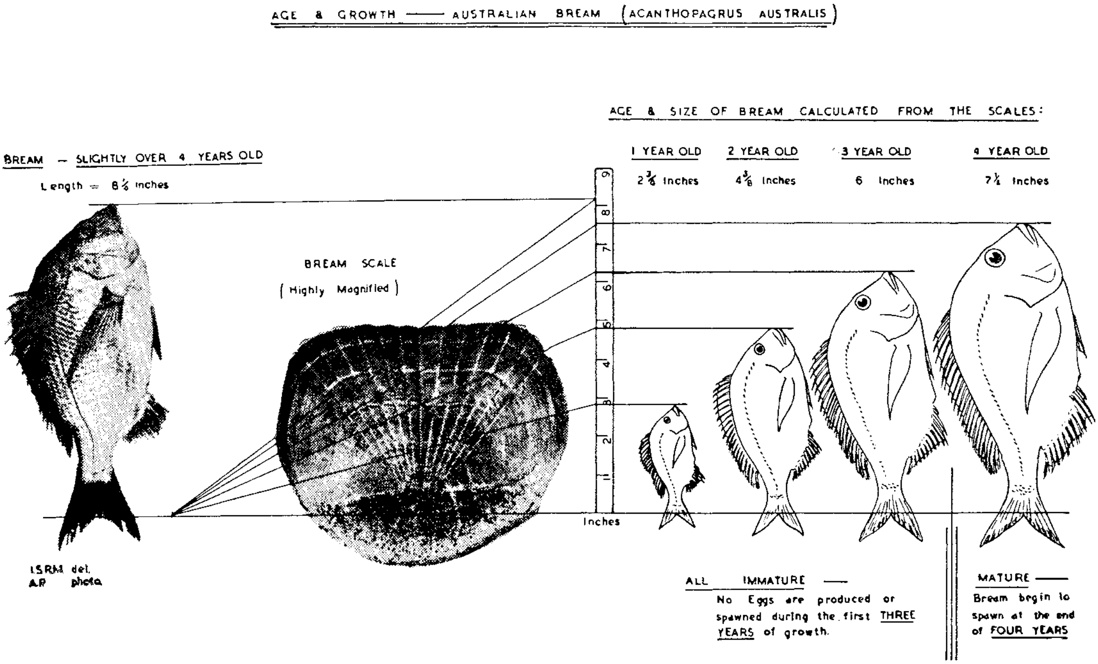
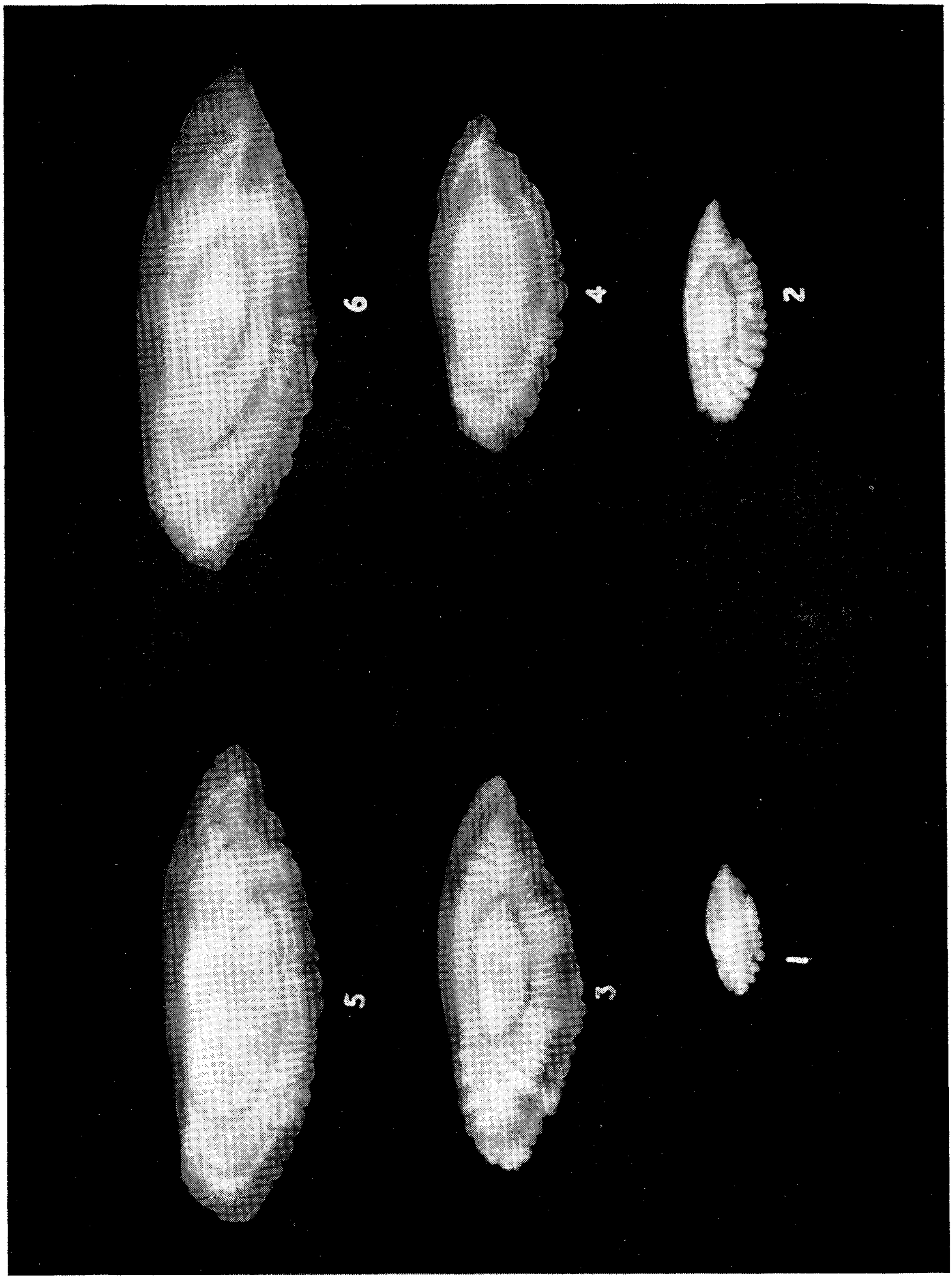


Fig. b


AGE & GROWTH —— AUSTRALIAN BREAM (ACANTHOPAGRUS AUSTRALIS)
AGE & SIZE OF BREAM CALCULATED FROM THE SCALES:
1 YEAR OLD
2 3/8 inches
2 YEAR OLD
4 3/8 inches
3 YEAR OLD
6 inches
4 YEAR OLD
7 1/4 inches
BREAM — SLIGHTLY OVER 4 YEARS OLD
Length = 8 1/2 inches
BREAM SCALE
(Highly Magnified)
Inches
ISRM del.
AR photo
ALL IMMATURE ——
No Eggs are produced or spawned during the first THREE YEARS of growth.
MATURE ——
Bream begin to spawn at the end of FOUR YEARS


6
4
2
5
3
1